AN INTEGRATED APPROACH TO THE EVALUATION AND MANAGEMENT OF CONTAMINATED SEDIMENTS

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AN INTEGRATED APPROACH

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OF CONTAMINATED SEDIMENTS

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The public was notified of the proposed *An Integrated Approach to the Evaluation and Management of Contaminated Sediments* through the Environmental Bill of Rights electronic registry and given the opportunity to comment in accordance with the Environmental Bill of Rights.

Table of Contents

Table of Contents (cont'd)

List of Figures

PREFACE

In June 1992, the Ministry of Environment and Energy published a set of guidelines for the protection and management of sediment quality in Ontario. Since that time, the need for specific guidance on assessing and managing contaminated sediment has been identified, especially in relation to the need for biological assessment tools for determining the severity of sediment contamination. The biological tests described in this document are not to be construed as the definitive tests, but rather as starting points in the assessment of sediment contamination. Other appropriate tests continue to be developed in this area.

This document has been developed to provide guidance on assessing sediment contamination, and where warranted, devising a management strategy for dealing with the contamination. The information in this document will be especially useful to RAP team members, and staff at all levels of government associated with sediment management.

This document is intended to provide guidance to the appropriate stakeholders on the technical aspects of sediment assessment and remediation, thereby facilitating public participation in the process. Determining the best course of action usually requires that the public be involved early in the decision-making process. While acknowledging the importance of stakeholder participation, this document does not provide specific guidance on the public participation process. This is usually developed on an issue-specific basis.

INTRODUCTION

This document is one of a series of reports associated with MOEE's sediment management strategy. Other documents describing separate facets of the strategy include-:

Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, which provides information on the development and use of chemical criteria for evaluating and classifying sediments.

Laboratory Sediment Biological Testing Protocol, which describes the laboratory protocol used to assess potential toxicity in sediments.

Sediment Assessment: A Guide to Study Design, Sampling and Laboratory Analysis, which outlines various sampling procedures used in collecting sediment samples and describes commonly used analytical laboratory techniques to determine contaminant levels in sediment.

Guidelines for Evaluating Construction Activities Impacting on Water Resources, which outlines various procedures and mitigative measures to minimize sediment loss during construction especially those activities associated with watercourse crossings.

A Tributary Assessment Protocol for Sediment Control (In Preparation), which describes assessment techniques used in determining the environmental "health" of a watercourse and measures to maintain or improve sediment quality within drainage basins so as to protect the local drainage system and prevent contamination of lower systems such as river mouths and the receiving lake systems.

This document, *An Integrated Approach to the Evaluation and Management of Contaminated Sediments*, outlines various considerations that together form the basis for sound decision making during sediment assessment and remediation planning.

The concept of ecosystem in the context of this document embraces the philosophy of full recognition of all components (biotic and abiotic) within the primary sediment medium-i.e. water or the aquatic system- and the close interrelationship between water and the other media (air and soil) to ensure that cross media pollution does not occur during sediment remediation.

The document describes in a stepwise fashion how to assess sediment and, where required, select the best available remediation option. In several sections of the report the information provided is a summary of detailed descriptions provided in the reports mentioned above or from other documents which are referenced as they appear in the text and which should be consulted if additional details are felt necessary.

Sediment remediation requiring either *in situ* treatment, or dredging and on-land treatment is a continually evolving field. Nevertheless, some of the efforts that have been expended in this area are now providing early dividends as far as new or improved approaches to sediment cleanup. Environment Canada, through the Great Lakes Cleanup Fund, is continuing to assess various promising sediment treatment technologies and has also been instrumental

in promoting the development of dredging equipment that is capable of removing sediment from the bottom of a watercourse without any appreciable loss to the waterbody.

Sound science is only a part of the decision making process associated with contaminated sediment management. The final decision as to the proper course of action must also be based on considerations of social and economic criteria, which are not within the scope of this document. This document is divided into six sections dealing with each of the major facets of a potential sediment remediation situation. Section 1 offers a brief overview of relevant legislation, Section 2 discusses data gathering, Section 3 covers data evaluation and findings, Section 4 addresses issues associated with sediment remediation and Section 5 discusses various remedial options. Section 6 provides a brief overview of the implementation of a cleanup plan while Section 7 notes the importance of port-remedial monitoring.

SECTION ONE---LEGISLATION

1.1 LEGISLATIVE REQUIREMENTS

Prior to commencing any remediation project, the necessary permits and approvals will have to be obtained from the appropriate agencies. Depending upon site-specific conditions, a project may require a number of permits or approvals from various government agencies and levels of government, all of which have jurisdiction within the same area.

For example, most large sediment removal projects undertaken by the Province will require an Environmental Assessment under the Environmental Assessment Act, though such projects can be exempted by demonstrating that they are undertaken in the public interest. Such assessments will have to identify potential effects of all aspects of the remediation project, as well as identifying mitigation measures, the consequences of not performing the project, etc.

Various types of approval may also be required for work in streams and lakes. For example, the removal of contaminated sediment from a stream using cofferdams and excavating equipment, may require approval under the Navigable Waters Protection Act, E.A. Act, the Public Land Act, and the Conservation Authorities Act.

Where the severity of the problem indicates that some type of remedial action will likely be necessary, applications for approvals and permits can be undertaken in the early stages of the project. Such applications can then proceed concurrently with assessment studies.

1.2 FEDERAL LEGISLATION

A number of federal Acts apply to remediation work and may require permits and/or approvals in order to carry out remediation projects. Federal legislation can be divided into two groups: federal legislation applying to all proponents, and legislation and policies applying only to federal government departments.

<u>Environmental Assessment and Review Process</u>

The Federal Environmental Assessment

and Review Process (EARP) is an Order-in-Council, intended to ensure that the impact of any federal project, program or activity is assessed early in the planning stages before commitments are made. The process applies to any proposal undertaken or financed by the federal government, involving lands (including the offshore) that are administered by the Government of Canada, or which concerns any proposal which has the potential to cause an environmental effect on an area of federal responsibility.

The federal proponent initiating a project is responsible for assessing the significance of the environmental impacts and public concerns, and the implementation of required mitigative measures. In addition, the proponent must satisfy all other legislation or regulatory requirements related to the development and implementation of the project.

EARP is due for replacement in 1995 by the Canadian Environmental Assessment Act.

Canadian Environmental Assessment Act

The Canadian Environmental Assessment Act (CEAA) will replace the Federal Environmental Assessment Review Process (EARP) when it is proclaimed.

The CEAA and its regulations set out the legislative responsibilities for the environmental assessment of projects that involve the federal government. The CEAA has four fundamental purposes:

- to ensure that the environmental effects of projects receive careful consideration before responsible authorities take action in connection with them;

- to encourage responsible authorities to take actions that promote sustainable development and thereby achieve or maintain a healthy environment and economy;

- to ensure that projects carried out in Canada or on federal lands do not cause significant adverse environmental effects outside the jurisdictions in which the projects are carried out; and

- to ensure that there is an opportunity for public participation in the environmental process.

An environmental assessment is required if a federal authority is required to exercise one or more of the following duties, powers or functions in relation to a project:

- proposes the project
- grants money to a project
- grants an interest in land to a project
- exercises a regulatory duty in relation to a project, such as issuing a permit or licence that is covered under the Law List regulation.

Similar to EARP, CEAA is based on the self-assessment of projects for environmental effects, by federal departments and agencies. The responsible authority may conduct an EA in the form of screening, class screening or comprehensive study.

Under a screening, a responsible authority has the greatest degree of management and flexibility over the scope and pace of the EA process. In cases where there is a sound knowledge of the environmental effects and appropriate mitigation measures for a group or class of projects, the responsible authority

may be able to use all or part of a class screening report. The majority of projects covered by the CEAA will undergo an EA through a screening.

Under a comprehensive study, the responsible authority also retains a primary management role over the EA, but has more obligations than in a screening. These include the need to consider a wider range of factors, submit the comprehensive study report to the Agency for review, take public comments into account and consider the need for a follow-up program.

If the screening or comprehensive study identifies the need for further assessment, the project must move to a public review in the form of either a mediation or panel review.

Canadian Environmental Protection Act

The Canadian Environmental Protection Act provides for the regulation of federal works, undertakings, and federal lands and waters, where existing legislation administered by the responsible federal department or agency does not provide for the making of regulations to protect the environment. In addition, there are provisions for the creation of guidelines and codes for environmentally sound practices and for setting objectives for desirable levels of environmental quality.

Migratory Birds Convention Act

The Migratory Birds Convention Act prohibits the disposal of any substances harmful to migratory birds in any waters or areas frequented by migratory birds. This Act would be applicable mainly in dredged material disposal.

Fisheries Act

The Fisheries Act has broad applicability to sediment remediation activities. Two sections of this Act are particularly relevant: Section 36 regulates the deposition of any substance (which would include contaminated sediment) which is deemed "deleterious", in waters frequented by fish. Section 35 regulates the alteration of fish habitat, including alteration, disruption or destruction of habitat (where habitat is defined as "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend, directly or indirectly, in order to carry out their life processes."). Although the administration of the Fisheries Act is the responsibility of the Department of Fisheries and Oceans, the administrative activity for Section 36 is carried out by Environment Canada and, through a long established understanding, Section 35 is administered by the Ontario Ministry of Natural Resources.

Any activities that can potentially disrupt fish or fish habitat are covered by this act. This includes all manner of in-stream or in-lake activities associated with sediment remediation projects.

Navigable Waters Protection Act (NWPA)

The NWPA prohibits any work on, in, upon, under, through or across a navigable waterway. "Work" has been defined to include the dumping of fill or the excavation of materials from the bed of navigable waters. An application for exemption is required for such projects, including dredging or disposal operations. Prior to granting the exemption, Transport Canada reviews the implication of the project for potential impact on navigation.

Great Lakes Water Quality Agreement

The Great Lakes Water Quality Agreement is an agreement between Canada and the United States to restore and enhance the water quality of the Great Lakes.

- Annex 2 of the Agreement relates to Remedial Action Plans to control and remediate areas where "beneficial uses" have been impaired and specifies the need for source control programs to reduce loadings of Critical Pollutants.
- Annex 7 of the Agreement relates specifically to dredging activities and specifies that the two governments will develop and implement programs and measures to ensure that dredging activities will have a minimum adverse effect on the environment.
- Annex 12 relates to the presence of persistent toxic compounds and stipulates that the governments shall take all reasonable and practical measures to rehabilitate those areas of the Great Lakes adversely affected by these chemicals.
- Annex 14 of the agreement provides for the governments, in cooperation with State and Provincial Governments, to identify the nature and extent of sediment pollution in the Great Lakes System and subsequently develop and evaluate methods to remedy such pollution.

1.3 PROVINCIAL LEGISLATION

Various Provincial Acts, administered by a number of ministries, will apply to sediment remediation activities.

Environmental Assessment Act

The Environmental Assessment Act (EA Act) applies to projects being carried out by the Province, municipalities, or public bodies. Specific private sector projects may be designated by regulation passed under the Act. The EA Act requires that the proponent of an undertaking subject to the Act must submit an EA document to the Minister of Environment and Energy. An EA document must include the following:

- a description of the purpose of the project, for example a problem or opportunity that the project is addressing;
- a description and statement of the rationale for the undertaking, alternatives to the undertaking and alternative methods of carrying out the undertaking;
- a description of the environment which may be directly or indirectly affected;
- the environmental effects; and
- the actions necessary to reduce, change, prevent or remedy the environmental effects of the undertaking, the alternative methods and the alternatives to the undertaking.

It is important to note that the Act defines "environment" to include all air, land, water, plant and animal life including humans; social, cultural and economic conditions; anything made by humans; or any solid, liquid, gas, odour heat, sound vibration or radiation caused by human activities.

The proponent of a project may make a written submission to the Minister of Environment and Energy requesting that a project which is subject to the EA Act be exempt under Section 29 of the Act. The request should outline the reasons why the project should be exempt, including the following:

- the overall benefits of the exemption
- the proponent's effort to involve the public, ministries and agencies to resolve disputes and to confirm that no major concerns exist;
- the potential for adverse effects; and
- whether or not legislation will adequately address issues.

The EA Act restricts that a licence, permit approval or consent required under any statute, regulation or by-law of the Province of Ontario, municipality or regulatory authority not be issued until the Environmental Assessment has been accepted and the undertaking has been approved under the EA Act.

Environmental Protection Act

The Environmental Protection Act regulates the discharge of pollutants (including "spilling") into the natural environment. The Act protects human health and plant and animal life against injury and damage and provides for the "repair" of any such damage. This Act has broad applicability to remediation activities.

Ontario Water Resources Act

The discharge of any material into water that may impair water quality or cause injury to any person, animal, bird or other living thing is prohibited by the authority of the Ontario Water Resources Act.

Beds of Navigable Waters Act

Title to the beds of navigable waters is restricted through grants by the Lieutenant-Governor. Ownership of lands bordering navigable waters does not provide right of use of the beds of those waters.

Public Lands Act

The management, sale and disposition of public lands, which includes the beds of most lakes and rivers as well as seasonally flooded areas, is controlled by the Public Lands Act. The Ontario Ministry of Natural Resources may define zones as open, deferred or closed for disposition. The Public Lands Act also regulates development, construction, or alteration of any public shorelands and this part may apply to remediation projects. All shoreline construction work will require a Work Permit issued by MNR under this legislation.

Conservation Authorities Act

The restricting or regulating of water through the construction of dams or diversions or depressions in rivers and streams and the placing and dumping of fill within the watershed is placed under the jurisdiction of the local Conservation Authority. This Act would be broadly applicable to flow diversions such as coffer dams, channelling, etc. as part of the remediation project.

Public Health Act

The Public Health Act is concerned with public water supplies and maintaining their quality to protect human health and assures that projects not impinge on the operation of water treatment facilities.

Lakes and Rivers Improvement Act

Approval for any work that consists of forwarding, holding back or diverting water (e.g., construction of coffer dams for stream remediation) is required from the Ontario Ministry of Natural Resources. Furthermore, the deposition of any substance or refuse into a lake or river or on the shore is prohibited by this Act.

Planning Act

The Provincial Wetlands Policy Statement, which was issued under the Planning Act addresses wetland protection and management within the land use planning process.

Mining Act

All aspects of mining activities within the province are regulated under the Mining Act.

1.4 MUNICIPAL LEGISLATION AND POLICIES

These will affect a project where shoreline or upland disposal is to be used. In these cases, municipal zoning or planning guidelines may have to be considered and taken into account. Since each municipality may have different requirements, the proponent is advised to contact the appropriate municipal office during the initial screening stage of the project. Contacting the municipal office will also permit the proponent to assess the need for public information sessions to facilitate public acceptance of the project.

SECTION TWO---DATA GATHERING

2.1 INTRODUCTION

Determining the potential impact of contaminants in sediment is a complex task since at any given location a variety of physical, chemical, and biological factors operate constantly over many years to create the existing environmental conditions. Although sudden dramatic changes, such as those induced by chemical spills, may create a shock to the system, most contaminated sediment problems have occurred over a number of years. During this time the system will usually have gradually adjusted to the changes that determined its current state.

Most natural systems possess an inherent resiliency which allows them to absorb changes without major disruption to the system. Few, however, are able to resist massive changes, though under such conditions most can continue functioning in an altered condition. This is primarily due to the ability of many organisms to adapt to varying degrees of contamination. However, while a contaminated system may appear to be functioning, it may in fact be severely constrained, and the effects may be felt beyond the immediate area. Therefore, consideration must be given to effects of the local situation on organisms that are not directly impacted, such as fish, which

frequent a range of sites. Impacts on organisms such as fish may be felt through the food chain by means of bioaccumulation processes, with consequent impacts on higher organisms and on human health.

Given that a problem area can affect a variety of uses within a much broader area, it is essential that data gathering for problem assessment utilize a variety of techniques that will provide the information necessary to answer a range of questions. At this time, it is important that all essential information be gathered. To avoid a "shotgun" approach to information collection, it is necessary to devise an adequate plan outlining the objectives of the study and the information needed to fulfil those objectives.

2.2 SEDIMENT ASSESSMENT-THE FIRST STEP

An awareness of a potential contaminated sediment problem is normally derived from information gathered during routine monitoring and surveillance operations or historical knowledge of past and/or ongoing sources. For example, in most of the RAP Areas of Concern sediment contamination has been identified through data gathered during monitoring and surveillance activities. In a number of cases, sediment contamination problems have been identified through biomonitoring studies, such as the Ministry's young-of-the-year fish monitoring program, the sport fish monitoring program, routine clam (mussel) biomonitoring programs and benthic invertebrate surveys. Such studies continue to be an important means of identifying and monitoring sediment contaminant problems. In some instances, such as chemical discharge associated with spills, specific studies will be required to determine whether the sediment in the affected area has been contaminated.

The most important preliminary piece of information necessary for sediment evaluation is chemical data, which are compared against the Provincial Sediment Quality Guidelines (PSQGs) as well as background levels. The Guidelines provide three levels of comparison based on effects on aquatic organisms. The No-Effect Level represents a level at which contaminants in sediment will have no discernible effect on aquatic organisms. Typically, it represents sediment that is very clean, which in most cases would exclude sediment found around urban areas and those impacted by industrial operations such as mining.

The next level is referred to as the Lowest Effect Level (LEL) and represents that level of contamination in sediments at which biological effects among sensitive organisms would first become apparent. Lowest Effect Level chemical concentrations are anticipated to adversely affect approximately five percent of the benthic organisms capable of inhabiting a given area. From a sediment management standpoint, the Lowest Effect Level is the point at which low-level concerns arise in relation to future worsening of the situation if existing sources are not controlled and would suggest the need for further biological testing. This level would rarely warrant concerns from a remediation standpoint unless dealing with a spill in areas where the background sediment is below the Lowest Effect Level.

The third level is the Severe Effect Level (SEL) and is the level that raises major concern from an environmental management

standpoint. The Severe Effect Level represents a level of chemical contamination potentially detrimental to approximately 95% of the benthic organisms capable of inhabiting a certain area. Management or decision-making options are presented in the Provincial Sediment Quality Guidelines. The urgency of a management response can be established by obtaining additional information through laboratory sediment bioassays on the toxicity of the sediment.

The importance of the First-Step sediment assessment is that it provides a good indication as to whether any further effort is required in studying sediment contamination in a given area.

2.3 POTENTIAL DECISIONS

Sediment evaluation is based upon exceedances of the Severe Effect Level of the PSQGs or of background levels. A single exceedance of the SEL can trigger a biological assessment. The implications of the exceedance will depend on the number of parameters exceeded, the level of exceedance and the toxicity or bioaccumulation potential of the compound(s). Exceedances of the LEL do not require a complete biological assessment, however, this does not preclude the need for such an assessment, and where a number of parameters exceed the LEL it may be prudent to conduct such an assessment.

Based on comparison with the PSQGs and background levels, there are three possible results from a First Step sediment evaluation:

- The sediment is clean (i.e., all parameters tested are below the LEL) and no further action is required unless the situation changes as a result of new discharges or material spills.

- The concentrations of contaminants in sediment are above the Lowest Effect Level and further testing is required. This will necessitate the gathering of additional information of a quality and quantity that would facilitate a thorough review of the site under consideration and may include both chemical and biological tests.

- The sediment has been shown during the First-Step assessment to have contaminant levels at or above the Severe Effect Level and biological assessment is warranted. The detailed studies must include laboratory biological testing for potential toxic effects as described in the PSQG document.

2.4 DETAILED INFORMATION GATHERING

This step should be considered if the information from the First-Step evaluation suggests the material exceeds the Lowest-Effect level of the Sediment Quality Guidelines. Prior to deciding on a course of action to obtain detailed information on a site, it is essential to ascertain the minimum information requirements for an adequate review. This can be best accomplished by clearly laying out the objectives of the proposed information gathering survey.

2.5 DETAILED STUDY OBJECTIVES

The sediment ecosystem is a complex

biogeochemical system that provides habitat for a variety of benthic organisms which form an integral part of the aquatic food chain. These organisms, many of which are sedentary and cannot escape life-threatening situations in their environment, can be eliminated through the toxic action of contaminants in sediments. Some organisms are more tolerant of contaminants in sediment and as a result they survive in contaminated areas, accumulate contaminants in their tissues and transfer them to higher predators such as fish. Contaminants in sediment can also have detrimental effects on water quality and water uses in the overlying water column. As a result, the objectives of sediment contaminant assessment studies would typically include all of these compartments.

General objectives of a detailed investigation will usually include the following determinations:

1. The degree of chemical contamination as well as local background and ambient levels.
2. The types of chemicals associated with the contamination.
3. The spatial extent, depth and boundaries of the contaminated area.
4. The biological significance (including bioavailability and bioaccumulation) of the chemicals and their levels.
5. The source/origin of the contaminants.
6. Physical factors that determine the movement of contaminants and contaminated sediments.
7. Rate and degree of temporal change in sediment or biological indicators (improvement or further degradation).

2.6 DEVISING A SAMPLING STRATEGY

Details on sampling strategy are provided in the MOEE document *Sediment Assessment: A Guide To Study Design, Sampling and Laboratory Analysis* (Jaagumagi and Persaud 1993). The information provided below represents the essential features of a sampling program.

The sampling strategy must be designed to specifically address the objectives of the undertaking and as such will vary according to the problem. The five objectives listed above, although generic, will apply to most situations.

Exploring issues associated with potential sediment remediation can be a challenging exercise. However, a large amount of information exists in published reports which can be used to provide a basis for establishing a sampling strategy. A number of these documents are listed at the end of this report and it is also very useful to consult those investigators who have had previous experience in carrying out sediment assessment studies. The information derived from such sources will help to save resources by avoiding some of the pitfalls associated with sampling and data gathering.

A key feature of a good strategy is to ensure that all information gathering is done concurrently. This would facilitate relating biological data to physical and chemical data and ensures that samples from a particular station truly reflect that station. It is always difficult, even with the best positioning devices, to locate a particular station in a subsequent survey.

Concurrent with environmental data

Figure 1: Contaminated Sediments - Approach to Problem Definition

Identify source(s)

- historical
- on-going

Design sediment sampling program

Identify contaminants of concern

Develop sediment map

Document contaminant characteristics

Compare to PSQGs and background levels

Determine toxicity potential and biomagnification potential

gathering, information should also be gathered on the sources of pollution to the area, the existing uses of the area and uses that are being impaired. Although it is necessary to gather as much information as possible, a serious effort should be made to focus data collection on fulfilling the specific aims of the study. The basic steps involved in the problem definition phase of such studies are outlined in Figure 1.

2.7 POSSIBLE COURSES OF ACTION

Objectives 1 and 2. Degree of chemical contamination and types of chemicals associated with the contamination

Before any sampling is undertaken, potential contaminants of concern will need to be identified. This will necessitate identification of all potential sources (both point sources and non-point sources). This would include some knowledge of the processes used at the potential sources (industrial processes, feedstocks, etc. for point sources; pesticide usage, etc. for diffuse sources) in order to determine which compounds will be of concern. Based upon this information, a sampling study can be designed, focusing on all the possible contaminants. The sediment concentrations of the potential contaminants will need to be determined through a sampling program and the severity of the chemical contamination assessed using available guidelines such as the PSQGs.

The second step in satisfying this objective will include a literature survey of the environmental fate of the contaminants, their potential transport pathways, and the potential toxic effects on aquatic organisms, including their potential to bioaccumulate and biomagnify. This type of specialized information is available within the Ministry from staff of the Standards Development Branch. This, in turn, will permit the identification of the major routes of exposure for aquatic organisms, and provide a basis for assessing potential risks. Where a number of contaminants are involved, some assessment of their interactive effects must also be considered. To a large extent, this has already been considered through the Provincial Sediment Quality Guidelines. Comparison with the PSQGs which will also help to place the degree of contamination into proper perspective by allowing the delineation of highly contaminated areas and areas of lesser degrees of contamination.

Objective 3. Spatial extent and depth of contamination

This step requires the delineation of the area affected. Within this objective, it is especially important to determine the outer boundaries of the affected area, since this will define the area of any future remediation. In many cases, it may be preferable to concentrate sampling density around the perimeter of the study area, especially if previous studies have adequately documented the existence of areas of contamination.

To enable determination of the volume of material, should remediation be required, it will be prudent to collect core samples rather than grab samples. Often it is most cost effective to collect and section all of the core samples during the initial survey. However, samples should not be stored for analysis beyond the period recommended by the analytical laboratory. Sample analysis can then proceed as needed. For example,

where a large area is being investigated, sample analysis can proceed in a step-wise fashion, with only those core sections selected for additional analysis where surficial sample results have indicated a sediment concern. Information derived from core samples could also prove useful in establishing "background" levels for contaminants such as metals (i.e. in those sections below the contaminated zone).

Details on sampling and sampling devices for chemical characterization of sediment can be found in the MOEE publication *Sediment Assessment: A Guide To Study Design, Sampling And Laboratory Analysis* (Jaagumagi and Persaud 1993) as well as those of other agencies.

A second and equally important aspect of sediment characterization, is determination of the physical environment of the area. In many cases, areas of contaminated sediment may act as sources of contaminated material to adjacent or downstream areas through resuspension of material. The potential for resuspension of contaminated material through erosion (i.e., through fluctuations in discharge, currents, wave patterns, and physical obstructions such as lakefill structures, dams, and weirs) needs to be carefully assessed. Characteristics such as seasonal and yearly net sediment erosion or deposition, which may affect subsurface contamination should be determined, since this will have a major impact on the determination of a remediation plan.

A number of sophisticated techniques for sediment characterization currently exist. Some are particularly suited to characterization of sediment type, such as side-scan sonar, while others are most effective for measuring the transport of sediment material to or from the area.

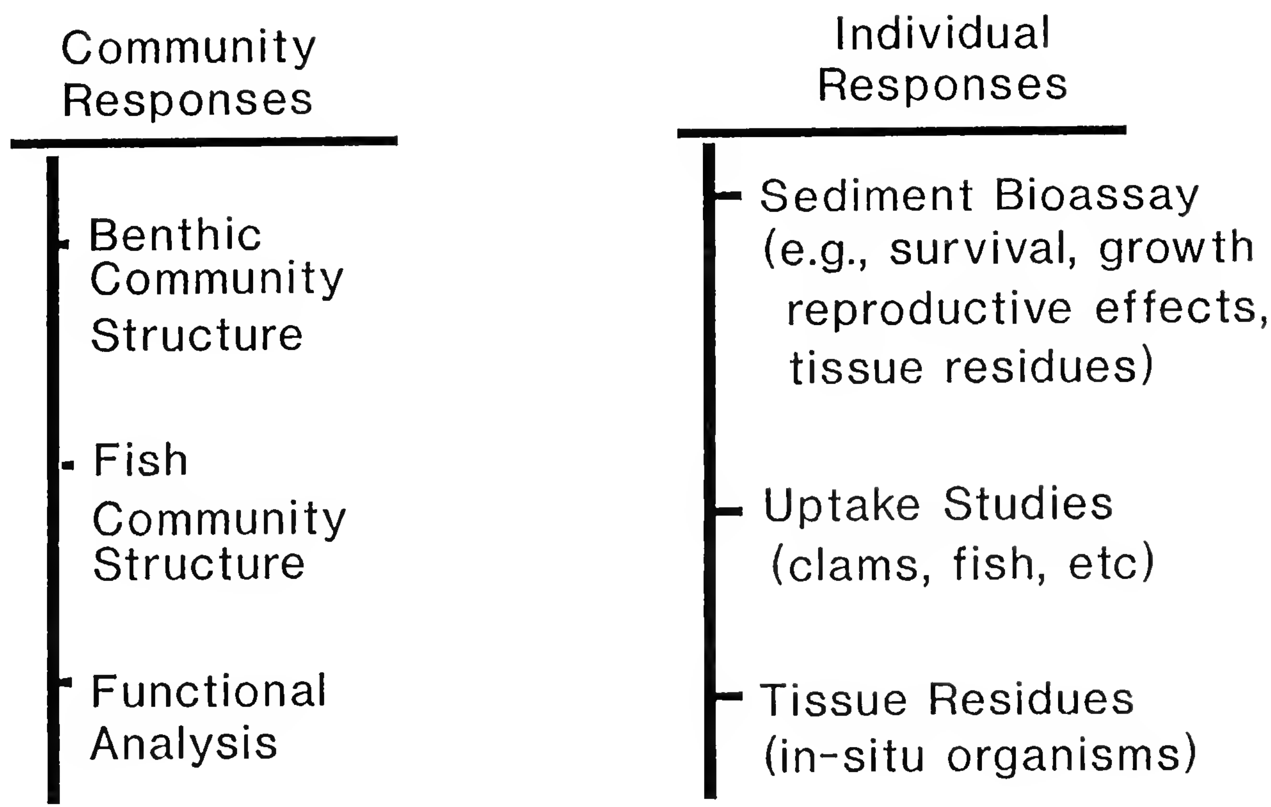
<u>Objective 4. The biological significance of the chemicals and their levels.</u>

An assessment of the severity of biological effects of contaminants in sediment is necessary in any potential remediation consideration. Biological assessment is normally required as part of the protocol for sediments that exceed the Lowest Effect Level or the Severe Effect Level. Such assessment should consider a range of organisms at different trophic levels of the aquatic system. The assessment of biological effects should also make use of information on potential effects on terrestrial organisms, particularly consumers (including human) of aquatic organisms such as fish. Such information is usually available through sport fish consumption guidelines, such as the Ministry's Sport Fish Contaminant Monitoring Program. The options involved in biological assessment are shown in Figure 2

Before any assessment of the severity of biological effects can be undertaken, the nature of the effects needs to be addressed. These can be broken down into two main groups, namely effects on individuals and effects on communities. A number of components are useful in this type of assessment, including:

- benthic community structure and functional analysis
- fish community studies
- sediment bioassays (including testing with water column organisms)
- uptake studies (e.g., caged fish and caged mussel studies)
- tissue resides in in-situ organisms (e.g., sport fish, young-of-the-year

Figure 2: Assessment of Biological Effects



fish, in-situ benthic organisms)

Information on biological effects is particularly important in deciding whether remediation should be considered. For example, a situation where a benthic community does not exhibit any direct toxic effect but, the contaminants of concern are persistent and bioaccumulative, may support consideration for remediation.

An important guiding principle in designing studies to assess biological effects is to utilize the practical, proven techniques that will provide information required to address the objectives of the undertaking.

A number of evaluation techniques are available to carry out a comprehensive biological assessment. These include:

1. Benthic and Fish Community Structure - Functional Group Analysis
   a. benthic community/functional group analysis. These studies consider the effects of contaminants at the population or community level. While generally unable to pinpoint a cause-effect relationship, they can provide a useful measure of overall ecosystem health.

   b. fish community studies. Like benthic studies, these can be used to determine contaminant effects on fish at the community or population level. In most cases, such changes are more indicative of land use changes than effects due to specific contaminants.

2. Sediment Bioassays.
   The sediment bioassay method makes use of benthic organisms such as chironomids, mayflies, oligochaetes, etc. and fathead minnows to assess chronic and acute toxicity of sediments. These studies can be designed to examine mortality, reproductive impairment, mutagenicity and a range of sublethal effects on individuals. They are most effective, however, in determining the potential toxicity of contaminated sediment (usually as a measured effect over a certain exposure period). As with benthic community/ functional analysis, the specific causative agent is difficult to isolate, especially when dealing with mixtures of contaminants. However, careful evaluation of all the available information can usually point to a causative agent or group of agents. The sediments used in these tests are usually disturbed, which in most cases makes the contaminants more available within the sediment and also through release to the water column. As a result, this test can be considered as representing the worst case scenario.

3. Uptake Studies
   This assessment method makes use of caged clams/mussels, leeches, and caged fish placed on, or suspended just above, the sediment to determine the levels of contaminants in the water column at the study site. Similarly, this approach can be applied in the laboratory through the exposure of cultured juvenile fathead minnows to test and control sediments. Both field and laboratory studies can provide a good indication of the release of contaminants to the water column from sediment. This information, therefore, is an indirect measure of the impacts of contaminants in sediment on water use impairments.

4. Contaminant Residues in In-situ

Organisms

a. benthic organism tissue residues. This method makes use of sediment-dwelling organisms to determine availability of contaminants from sediment. In most cases, sediment ingesting organisms are chosen, since these are most likely to accumulate contaminants directly from the sediments. This provides a measure of the availability of contaminants to biota, and the potential for transfer of contaminants through the food chain. Coupled with the clam studies, it can provide an indication of the relative importance of the water and sediment pathways for bioaccumulation.

b. fish tissue residues. Fish tissue residues (bottom-feeding fish and young-of-the-year) are commonly used in conjunction with other tests to determine the availability of contaminants to higher predators (fish tissue levels are compared with available guidelines, e.g., Health Canada, IJC, Newell *et al.* 1987). Together with clam/mussel biomonitoring, benthic tissue residues, and laboratory organism tissue analysis, this information can be used to determine primary exposure pathways of contaminants in sediment. It should be noted that with fish, uptake can be through desorption from the sediments and subsequent adsorption to tissues as well as through ingestion of contaminated food.

c. sport fish consumption guidelines. The tissue residue levels in sport fish represent a direct danger to humans through consumption of contaminated fish. Levels for safe consumption of fish species are developed by Health Canada and the MOEE, based on contaminant levels and consumption patterns. Levels are designed to protect human consumers, but also provide an indication of the availability of contaminants from sediments and other sources such as food.

The results of a combination of the above studies will provide a good indication as to whether the study area under consideration presents a danger to biological organisms including humans. This type of approach is necessary, since no single indicator can provide all the necessary information for management decision-making. This type of information will also assist in determining where to concentrate any remedial actions.

Objective 5. The source or origin of contaminants.

Concurrent with environmental data gathering, efforts should be made to obtain information on contaminant input to the area. Various strategies can be used to obtain such information, including previous studies, a knowledge of the industries in the area, known events of spills, etc. In urban areas a characteristic set of pollutants can be expected to be encountered, covering a wide range of chemicals. Outside urban centres, and especially in the vicinity of particular types of industries, the chemicals characteristic of the local industry will prevail. A knowledge of the processes is useful for determining which contaminants are likely to be of concern.

The usual sources of contaminants can be grouped into municipal (which will likely contain the widest range of chemicals), industrial, urban runoff, agricultural, mining, and atmospheric fallout. Becoming familiar with the sources will provide a good framework of the type of chemical analysis required and will also aid decision making on remediation. In some instances it may be necessary to test material emanating from such sources to determine their current toxic impact.

Objective 6. Physical factors that determine the movement of contaminants and contaminated sediments.

In order for a complete assessment of options to be undertaken, particularly for areas that have high energy water movement such as rivers and shorelines, an understanding of sediment dynamics should be attempted. This may be straight forward or extremely complex, but becomes increasingly important, particularly if the Natural Remediation option (Section 5) is considered.

Techniques for measuring sediment dynamics vary in their sophistication and ability to provide useful information. The data generated by the various techniques may include: depth profiles of soft sediments; sediment particle size; current velocity at the sediment/water interface and; sub-bottom profiling. In many cases such data are analyzed through the use of models that can help predict sediment movement under different physical conditions.

Objective 7. Temporal changes in biological and chemical factors.

In many locations, particularly where historical contamination exists, improvements in levels of contamination can occur over time as stable compounds are formed or as contaminants are decomposed. Similarly, biological conditions can improve over time, usually as a function of changes in contaminant concentrations. Detecting such changes is usually accomplished through studies such as trend analysis. Changes in the contaminant status or biological effects over time will directly affect the choice of remedial option, and may determine whether active remediation is necessary. Conversely, if conditions continue to deteriorate over time, this may point to additional sources in the area or for the need for more effective source control. It may also provide a strong indication of the need for active remediation.

Information from previous studies therefore plays a significant role in the evaluation of sediment conditions and may be a major consideration in assessing the need and extent of sediment remediation.

SECTION THREE -- DATA EVALUATION

3.1 DATA EVALUATION

The results obtained from field surveys and laboratory analyses need to be carefully evaluated since in many cases this will be the critical point for further decision making.

A good first step towards evaluation of the survey data would be a summary of the sediment chemistry information showing how the data compare with the Provincial Sediment Quality Guidelines as well as background levels. In this initial round of evaluations, stations that exceed the Severe

Effect Level should be identified as an area of major concern. The information summarized in the table can then be represented on a diagram of the study area designated as clean, contaminated and of major concern (highly contaminated) as shown in Figure 3. An hypothetical example of such an evaluation is presented below:

> The results of a sediment sampling program comprised of 10 stations yielded only one area where contaminant levels were of concern. The results are presented in Table 1.

Table 1 Sediment Chemistry Summary
STATION #1

Parameter	Value ug/g	PSQG Comparison	Concern
Cu	80	>LEL	M
PCB	50	>SEL	H
Zn	60	<LEL	L

Level of Concern:
<LEL= Low(L) >LEL<SEL= Moderate(M)
>SEL= High (H)

> In addition to sediment chemical analysis, biological assessment was also undertaken using a number of tests, such as sediment bioassays (required when sediment concentrations exceed the SEL). The results of these tests in the hypothetical example are presented in Table 2.

Table 2
Biological Test Result Summary:

Biological Test	Test Result Summary	Concern
Lab Bioassay	60% Mortality	H

Table 2
Biological Test Result Summary: cont'd

Biological Test	Test Result Summary	Concern
	Significant accumulation above sediment levels	H
Benthic community	Poor distribution chemical effects suspected.	H
Benthic organism tissue residues	Significant accumulation	H
Sportfish data	None available	
Caged clams	No significant accumulation	L

MAP INFORMATION

Figure 3

At this stage, it is important to determine whether the levels, especially for metals, are reflective of background or

anthropogenic inputs. Information gathered from core samples, as discussed in the last section, can be used for this purpose. Core derived information can also be tabulated to show possible variation in contamination with depth of sediment.

The next steps in the data evaluation process will involve an evaluation of each test or study (referred to below as confirmatory information) and making a comparison with the findings in Table 1. Where the information supports that of Table 1, a simple confirmation can be noted. Where the information shows conflicting results, a careful analysis should be carried out to determine the reasons for the apparent conflict. This step will require a good knowledge of the subject area by the investigator or reliance on experts in the specific subject.

In the above hypothetical example, both high sediment concentrations of contaminants, especially bioaccumulative compounds such as PCBs, and biological effects point to the need for consideration of sediment remediation.

The final step in data evaluation will involve integrating the results of the physical assessment of the area with the biological effects data. The results of such evaluations are most easily determined through the production of detailed maps, incorporating chemical analysis data for sediments (showing the extent and depth of sediment contamination), the biological effects within the identified areas, and the physical forces, such as erosion or deposition, to which these areas are subject.

3.2 CONFIRMATORY INFORMATION

Laboratory Sediment Bioassays

Sediment bioassays are normally carried out to provide some indication of the toxic effects of sediment on sediment-dwelling and water column organisms through the direct measurement of multiple biological effects. Sediment bioassays can also be used to determine bioavailability of sediment-sorbed contaminants to sediment-dwelling and water column organisms (see Uptake Studies, this section). However, since the sediment samples used for these tests are disturbed, the contaminants will usually be more readily available to both the bottom dwelling and water column organisms and will not necessarily duplicate in-situ conditions.

The results of a sediment bioassay need careful interpretation and should be carried out by an individual with expertise in the performance of sediment toxicity testing. (The results from the MOEE sediment bioassay laboratory are normally reported in a fully interpreted form). A number of factors can affect the test results, such as physical characteristics of the sediment, water quality, and the presence of indigenous organisms, all of which require careful interpretation to ensure the test results are meaningful. At the outset, arrangements should be made to report the results on a station by station basis.

Laboratory bioassays, and in particular static tests, usually reflect a worse case situation. Due to the controlled conditions under which such tests are conducted, they usually do not duplicate the conditions that would exist under a natural setting. As a result, they should not be used as the sole

basis for decision making. As a confirmatory tool to be used with sediment guidelines and other tests, they have proven to be very useful.

In using bioassay results, a useful approach is to compare the results from each station with the chemistry results for that station. In those cases where high sediment contamination shows a negative biological response, it can be assumed that the test confirms the chemical results. In those instances where the bioassay results do not support the normally expected response to the contaminants in the sample, a careful examination for the possible reasons should be made. Such examination should be carried out after all the other confirmatory tests have been evaluated.

Details on conducting sediment bioassays are available in the Ministry publication *Ontario Ministry of the Environment Laboratory Sediment Biological Testing Protocol.* (Bedard et al 1992) as well as publications of other agencies.

Benthic Community Assessment

Benthic population studies are conducted to determine the types and abundance of organisms living in the sediment under study to determine whether contaminants are affecting their survival. Under natural situations, a variety of physical, chemical and biological processes operate on an ongoing basis to shape the environment an organism occupies.

In some cases, the physical attributes, such as substrate type, will determine which species can survive in a given area. In certain instances, pressures from competing species will be the limiting factor, while in other situations the contaminants in sediment will have a major impact on certain species.

It has been found that some organisms are able to adapt to low levels of contaminants with subsequent generations developing a greater tolerance for higher levels of those contaminants over time (Klerks and Levinton 1989). It should also be pointed out that many other factors, such as oxygen and nutrient levels, can also exert a profound influence on benthic organisms.

Due to the complexity involved in assessing benthic community data, it is essential that an investigator with a strong expertise in the subject area assist in the interpretation of the data.

The information obtained from benthic community studies must also be compared with chemical results and laboratory bioassays as a confirmation of those findings, since all study components have their own strengths and weaknesses. A weakness of benthic community studies, for example, is that such studies do not provide any indication of the ability of certain chemicals to bioaccumulate through the food chain.

In many situations, organisms living in contaminated sediment will not show any direct impact as a result of contamination. They may, however, take up and accumulate low levels of certain chemicals which can then be passed on to higher organisms and subsequently to humans through, for example, fish consumption. The next set of tests will provide a means of assessing such potential of contaminated sediments.

Procedures for conducting benthic

community assessments are described in the MOEE document *Sediment Assessment: A Guide to Study Design, Sampling and Laboratory Analysis* (Jaagumagi and Persaud 1993). In addition, a large body of information exists in the published literature on conducting such studies and interpreting the results.

Uptake Studies using Introduced Organisms (caged mussels/leeches/fish)

Caged specimens are often used in monitoring the levels of contaminant uptake in the environment and in assessing in-place toxicity. These tests can also provide some indication of contaminant movement through the food chain, which is often a key factor in decision making on sediment remediation.

Selectively placing organisms for specific exposure periods and subsequently analyzing their tissues for contaminant levels provides a good indication of contaminant availability from the water column in comparison to release from sediment and the potential to affect organisms higher in the food chain. However, these methods are only applicable where sediments are the only on-going sources to the water column and external sources have been controlled. Where sources to the water column have not been controlled, these methods are most likely to measure effects from these sources.

Similar studies can be undertaken to determine toxic effects through assessment of chronic or acute endpoints. Such studies usually make use of introduced organisms placed for set periods of time.

Information gathered from these tests relate more to how localized contamination may affect non-native organisms rather than local organisms. This information can be used in risk assessments or in flagging concerns during remediation deliberations.

Uptake studies can also be undertaken in the laboratory as part of sediment bioassay testing. Through the analysis of tissue residues on test organisms, sediment bioassays allow for the measurement of differences in chemical bioavailability of sediment-sorbed contaminants among sites.

Details on conducting uptake studies using mussels are described in Hayton *et al* (1991). Methods for conducting field-based fish toxicity tests are available in Flood *et al* (in press) while laboratory test procedures for examining chemical bioavailability are described in Bedard *et al* 1992.

Uptake Studies using In-Situ Organisms (Tissue Residue Analysis of Benthic Organisms/ Bottom-feeding Fish)

Another approach to determining bioaccumulation potential is to collect sufficient quantities of native organisms and analyze for the levels of contaminants in their tissues.

In using benthic organisms or fish (e.g., young-of-the-year fish), different modes of uptake are considered for each organism. Benthic organisms tend to accumulate contaminants directly from the sediments through ingestion, while fish can accumulate contaminants from both ingestion of contaminated food (benthic organisms) or from the water column (ingestion and adsorption).

Procedures for benthic organism tissue residue analysis are described in the MOEE document *Sediment Assessment: A Guide to*

Study Design, Sampling and Laboratory Analysis (Jaagumagi and Persaud 1993). Procedures for young-of-the-year fish studies are available in the MOEE publication *Organic Contaminants in Forage Fish from Toronto Area Streams.* (Suns and Hitchin, 1994).

Sport Fish Data

The Ministry of Environment and Energy and the Ministry of Natural Resources collect sports fish information for a number of locations across Ontario. This information can be a useful tool in gauging which contaminants are being accumulated and therefore, are of general concern. Since sport fish are normally not restricted to a particular area it is difficult to determine the relative contribution of contaminants from sediment at a given location. However, it is safe to assume that specific bioaccumulative compounds will have an impact on fish.

The information obtained from sport fish data has a direct bearing on potential impacts to higher organisms that consume fish, including humans. A general assumption that contaminants which are found at high levels in fish are of concern when they are found in sediment will place such chemicals in proper perspective when evaluating sediment chemistry. Although information on contaminants in sport fish cannot be used to show a direct impact, it can be used to identify a potential risk of biological effects. The degree of concern associated with such risk can be evaluated in light of the other information collected on the study area.

Sport fish information can be obtained from the Guide To Eating Sport Fish in Ontario and by contacting the office identified in the guide for additional information.

There are no clear rules for selecting the appropriate biological tests. In some cases, depending on site-specific considerations, certain tests will be interchangeable. For example, analysis of young-of-the-year fish and clam biomonitoring may provide similar information at some sites. Often, the choice of a particular biological test will depend on such considerations as type of contaminants, cost, ease of sampling and availability of suitable substrate or other physical factors. However, a primary consideration in choosing the biological test should be to determine how definitive the test results are likely to be. In many cases this is difficult to predict in advance and most studies will include a number of tests to ensure sufficient data have been collected on which to base management decisions.

Physical Environment

In those locations where sediment contaminant concentrations and biological effects point to a need for consideration of remedial action, the nature of the physical environment will need to be assessed. This will usually involve measures of transport to and from the area, both as suspended sediment and bed sediment. A variety of sediment traps and gauging methods can be used to measure deposition over extended periods of time (seasonal or yearly), as well as more sophisticated sonar techniques which can be employed to rapidly map out large sections of the substrate (primarily used to determine sediment type, and hence the potential for erosion). This type of information can be particularly important in determining whether contaminated sediments

Determining the Need for Sediment Remediation

Determine Severity of sediment contamination
- exceedances of Severe Effect Level
- exceedances of Lowest Effect Level
- area of sediment exceeding guidelines
- depth of sediment exceeding guidelines

Determine severity of biological effects
- toxic effects (acute and chronic) on sediment organisms
- toxic effects on water column organisms
- bioavailability from sediments

Determine physical factors
- erosion or deposition of material
- characterization of sediment types

Determine other impaired uses
- effects on fish and wildlife
- effects on habitat

Determine potential to control sources
- without prior source control, remedial actions will be counterproductive

Determine local "best uses"
- assess local land use

can be left to undergo natural remediation (discussed in Section 5).

Results from such studies can often be plotted in 3-dimensional form, to provide a view of the extent and volume of sediment affected.

3.3 EVALUATION

After summarizing the information collected through field studies and laboratory analyses, the next step is the careful evaluation of the information. The following points may prove helpful in putting the information in proper perspective.

- chemical analyses provide information on the concentration of contaminants in sediment that may be harmful to biota.

- sediment bioassays provide information on the relative bioavailability and toxicity of sediment bound contaminants under laboratory conditions where the effects of many natural environmental factors are controlled. However, such tests may also show that a certain sediment is toxic to the test organisms, while under natural conditions the same organisms may be surviving in these sediments.

- benthic community data provide corroborating evidence from resident biota on the major compositional alterations to a component of the ecosystem under *in situ* conditions. (However, the effects observed may in some cases be due to factors other than sediment-bound contaminants.)

- *in situ* organisms collected for tissue analysis provide an indication of availability of contaminants in the sediments to biota, and identify potential pathways for movement into the food chain.

- sport fish and young-of-the-year fishprovide a list of substances with bioaccumulative potential and the degree of their availability for uptake from the water column, respectively.

- caged specimens (fish and mussels) provide information on availability of contaminants from the sediments to the water column, as well as information on direct toxicity to water column organisms.

- physical measurements provide information on sediment types and potential contaminant movement or isolation.

The information obtained from these studies provides sufficient basis to characterize any given area. The data are complementary to each other and provide sufficient empirical evidence on both the degree of contamination and the potential effects that could result from such sediment. From this the relative quality of the sediment can be ascertained.

It is not uncommon to find that certain tests show conflicting results with other tests. As an example, a bioassay study may show a certain sediment to be toxic to the test organisms, while under natural conditions the same organisms may be surviving in that sediment. Survival alone should not be the final criteria, since the organism may have accumulated contaminant residues that could potentially be transferred to higher organisms. In addition, there may be other effects such as reproductive impairment and reduced growth.

There are several possible explanations for differences between laboratory and field derived data and the investigator must be familiar with these or seek advice from specialists to avoid erroneous deductions and perhaps costly recommendations.

A summary of the factors to be considered in determining the need for sediment remediation are presented in the inset on page 23.

3.4 FINDINGS

Having reviewed the data gathered on the site the investigator must provide the scientific basis that will assist decision makers as to the proper course of action in dealing with contaminated sediment.

To this end, a number of points should be considered and the results evaluated. As part of this evaluation, a number of issues will arise and these should be addressed:

Sources:

- Presence of active sources to the area.
- Types of contaminant sources - point sources or non-point (diffuse) sources.

Contaminant concentrations:

- Sediment contaminants exceed LEL for 1 or more contaminants.
- Sediment contaminants exceed SEL for 1 or more contaminants.

Contaminant characteristics:

- Types of contaminants - i.e. nutrients, metals, organics.
- Presence of contaminants as a mix of metals and/or organics.

Biological effects:

- Characteristics of benthic community - benthic organisms abundant and evenly distributed or benthic invertebrate community is species poor and consists mainly of pollution tolerant organisms.
- *In situ* and laboratory biological tests and sport fish data show uptake of contaminants.
- Sediment results in chronic effects on aquatic organisms or is acutely toxic.

Physical factors:

- Sediment type - i.e., presence of fine-grained material (sand/clay/mud).
- Physical characteristics of the area - i.e., depositional or erosional.
- Presence of factors that may alter the physical nature of the site (e.g., lakefills, flow changes,etc.).

Temporal factors:

- Changes in contaminant concentrations over time.
- Changes in biological effects.
- Changes in physical characteristics - i.e., changes in flow dynamics resulting in alteration of erosional or depositional areas.

Where contaminant levels are above the SEL and are due to local sources then a prime consideration would be to seek reductions in or elimination of those sources.

In instances where some or all of the biological effects studies yield negative results then the reasons for such findings must be fully explored. This will require an in-depth assessment of the information and knowledge and experience of sediment related science. As an example, the results may indicate that only certain species of benthic organisms are present. However, while the sediments are contaminated, the benthic results may be more reflective of substrate type or nutrient\organic enrichment rather than direct chemical effects. Similarly, the presence of benthic species in good abundance and distribution may suggest a healthy system, but bioaccumulation studies may show contaminant uptake with potential implications to other organisms in the food chain including humans.

Equal care should be given to

interpreting the results of laboratory sediment bioassays. In cases where significant adverse effects have been noted, effort should be directed towards determining whether this is in fact due to chemical factors, rather than physical factors, such as unsuitable sediment type. For example, a combination of contaminated sediments and unsuitable sediment type could result in a combination of stresses on the test organisms which, individually, would not have elicited such a severe response.

If the study finds that the sediment in a given location poses environmental or potential human health problems, then remedial action should be considered.

SECTION FOUR -- DEVELOPING AN ACTION PLAN

4.1 CONSIDERATIONS GOVERNING SEDIMENT REMEDIATION

Scientific information can be used to designate a site with contaminated sediment as a potential candidate for remediation. The actual decision as to what specific action is required involves a host of other considerations and some form of "risk management" procedure may help in the decision making process.

A sediment remediation plan is comprised of a series of carefully laid out steps designed to achieve a desired goal or objective. The most common goal is reducing sediment contamination to an acceptable level. The actions contemplated in the plan must be based on the ecosystem concept to ensure that short term gains do not cloud potential long term problems or that problems are not shifted from the aquatic medium to an upland site. In this regard, the consequences of each proposed action to be taken must be fully evaluated before the plan is adopted.

Since continued inputs of contaminants to an area to be cleaned up will be counterproductive to an effective remedial effort, the most essential feature of any cleanup plan is the control of contaminant sources to the area. As noted in the previous section, all sources of contaminant input must be identified and, where possible, their contribution quantified in order to develop sound source control measures.

Following effective source controls, other sediment remedial actions may be taken to speed up recovery. There is evidence that natural restoration will usually proceed once the sources are controlled. This process, which relies on clean sediment covering over the contaminated material, may require several years. In areas where the supply of incoming sediment is low, other forms of *in situ* restoration may be needed to speed up the recovery process.

Within the last few years, various sediment clean- up technologies have undergone testing to determine the capabilities of removing and treating contaminated sediment. A summary of findings to date is provided in Section 5. These technologies have been tried on relatively small volumes of sediment which makes it difficult at this stage to assess their cost effectiveness on large projects.

Within Ontario, most sediment cleanup operations have traditionally involved some form of dredging and confined or upland

disposal, and most of these have been in response to chemical spills. It is now clear that suitable new sites for the placement of large volumes of dredged material are generally rare and existing waste disposal facilities such as sanitary landfills are approaching or already at capacity in most areas.

Where suitable disposal sites are available, such as in the vicinity of major Great Lakes harbours, dredging and confined disposal may still be the preferred option for sediment cleanup, at least until better solutions are found. This is because much knowledge and experience has been gained using this technique and it is not restricted by the volume of material to be removed, as are some of the newer techniques which are now evolving towards a large production scale.

4.2 SETTING A GOAL

The International Joint Commission has identified a number of "use impairments" in its "listing/delisting" criteria for Great Lakes Areas of Concern. These include:-

- Restrictions on fish and wildlife consumption.
- Tainting of fish and wildlife flavour.
- Degraded fish and wildlife populations.
- Fish tumours or other deformities.
- Bird or animal deformities or reproductive problems.
- Degradation of benthos.
- Restrictions on dredging activities.
- Eutrophication or undesirable algae.
- Restrictions on drinking water consumption or taste and odour problems.
- Beach closings.
- Degradation of aesthetics.
- Added costs to agriculture or industry.
- Degradation of phytoplankton and zooplankton populations.
- Loss of fish and wildlife habitat.

Sediments alone may not contribute directly to this extensive list of use impairments but, through the slow release of contaminants in some areas, may be a source of chemicals to the water column. To progress from a contaminated sediment problem to the restoration of designated uses in an area will require a strategy that involves a phased approach, likely over several years, to achieve significant improvements. It must be remembered, however, that a problem which has been in the making for decades may not be solved quickly. It is imperative, therefore, that any cleanup goal aimed at use restoration be based on a realistic schedule that incorporates source controls and the practical constraints of removing or covering over contaminated sediment until a desired concentration is achieved.

Another consideration of a practical nature is that current technology can only handle small volumes of material within reasonable costs. This suggests that it might be more practical and economically feasible to deal initially with the zones of high contamination, often referred to as "hot spots", while addressing the remaining portions of the area as financial and other constraining factors become more favourable. The important aspect of sediment management at this stage is to set realistic goals based on the practical nature of the options for achieving the goals, as well as the social, economic and environmental costs and benefits of achieving the goals. Such

analysis must also consider the "do nothing option". The rest of this section describes some of the factors that may be considered in setting cleanup goals.

Factors to Consider in Setting Cleanup Goals:

The nature of the area and the problem

- The size of the area affected needs to be clearly defined since this will have a significant bearing on the remedial option chosen from both a cost and technology perspective.

- The uses the area is put to and the potential for this area to affect adjoining areas through the spread of contaminated sediments.

  Uses may include protection of fisheries and benthic organisms. There is a need to consider both the toxic and bioaccumulative potential of contaminants. In previous sections, the need to look at a range of tests was indicated. This becomes critical at this stage since the severity of the effect will play a major role in arriving at the final decision.

  From a human health perspective, compounds that are persistent and pose a threat to water supplies or fish and wildlife will be weighted differently from compounds that do not pose similar threats. In some cases recreational/aesthetic considerations may be the driving force in a cleanup study.

- The potential for recontamination must be examined from the point of view of existing and proposed land use and source controls. Existing and new industries must incorporate features that will not lead to sediment contamination. It will be prudent to view this aspect not only from a local perspective but also from a broader watershed or regional perspective.

- There is a need to consider whether sediment removal will create additional problems, such as the exposure of historical contamination in deeper layers of the sediment. Care must be taken to ensure that the full depth of the problem has been adequately defined.

- The physical environment of the area needs to be considered. The potential for resuspension of contaminated sediment, with resultant contamination of adjacent or downstream areas will be an important factor in developing a remediation plan.

The Nature of the Solution:

The solution to the identified problem in the area under investigation must be based on a clear understanding of the problem by all members of the decision making team. Science provides a large measure of the problem definition but often cannot be comprehensive enough to provide answers to all the questions that may arise. This is the state of the art and even scientists recognize the shortcomings and rely on tools such as risk analysis to provide a structured basis for decision making. Members of the decision making team may experience difficulty in weighing the "apparent conflicts" that arise from considering all the results such as sediment chemistry, benthic surveys, toxicity testing, fish tissue residue, etc. This is

especially troublesome when one assessment technique suggests a problem and the others do not. For this reason the *Provincial Sediment Quality Guidelines* provide a good basis on which to conduct an evaluation. It is a stepwise process that employs a number of techniques, thus eliminating the chances of arriving at erroneous conclusions.

In deciding on a rationale for cleanup, the cleanup objectives may not be realized over the short term and should realistically be viewed as longer term objectives, recognizing also that some of the uses identified may never have existed in the area.

Setting a Framework for Action:

With the exception of spills, which must be cleaned up immediately, the most urgent need in environmental management is to protect the ecosystem from further abuse. Thus, source control must be the foundation of remedial action.

Consideration of remedial action in an area of contaminated sediment requires the development of a cleanup goal. This goal should be based on the "desired state of the environment" or developed in support of certain "attainable" uses. These need to be evaluated within the context of the whole watershed (i.e., a holistic approach). Where feasible, chemical guidelines provide a very convenient tool for setting cleanup goals though these must be used with care, since most chemical guidelines have been developed for broad use and may require some adjustment when applied to specific sites. The final goal could also include intermediate goal, since the achievement of the goal can be phased over time or over a sequence of activities.

The steps involved in developing a cleanup plan have been summarized in the inset on the following page.

The ideal cleanup goal will always be the level that provides for the protection of all sediment uses. In most cases the target will be determined by the local background or ambient values, since these are the practical limits to cleanup. However, cleaning up to this level will not always be feasible, especially when the area under consideration is large or where there are ongoing sources of contamination. Such areas may require a multiphased approach, with a lengthy time frame, to achieve source control before any remediation work is undertaken.

In some areas, the ideal cleanup opportunities present themselves and these should not be overlooked. For example, Collingwood Harbour remedial efforts (i.e., dredging) were assisted by the presence, on-site, of facilities designed for navigational dredging that were ready to accept the sediment. Such ideal situations may not exist in all areas, however, all options must be explored.

If cleanup cannot be accomplished in a single operation, then a sequence of operations should be planned and for each one a plan should be developed on what is to be achieved within a given time frame. The plan should be based on the following:

- The cleanup plan must be based on realistic goals. If the goal is too low or cannot be achieved within practical economic limits, then the effort will be of little practical value.

Development of Remediation Plan

Base need for remedial action on biological effects and contaminant concentrations
- severity of biological effects
- ambient water and sediment quality
- types of contaminants

Determine effectiveness of source controls for all sources
- ability to control sources will affect final remediation target

Need to consider local land use and local "best use"
- goal should be reasonably achievable
- compatible with existing land uses

- The cleanup goal must be compatible with the prevailing land and water uses in the area. The existing uses of the area will influence the final remediation target. For example, an area receiving stormwater runoff from an urban area will require a different cleanup target from one influenced mainly by rural activities.

- The plan should be compatible with proposed local land uses. The proposed uses of the adjoining areas and perhaps the local watershed will influence the remedial plan. For example, an area that is used exclusively for recreation will be considered differently from one with mixed uses.

- The plan must consider the quality of sediment entering the area from remote sources such as upstream areas. This is especially important in enclosed areas such as harbours where most of the sediment that enters the area is deposited. It will be counter-productive in such cases to cleanup existing sediments when the problem could recur over a short time.

- The nature of the contaminants will

play a role in target setting. The significance of potential health and environmental effects of contaminants in sediments is determined to a large extent by the types of contaminants encountered. Some compounds, such as the persistent organics, will pose a greater environmental threat and will therefore elicit a different response from decision makers compared to certain metals.

- The goal set will also be influenced by cleanup technology, suitable disposal sites for sediment if the removal option is selected and equally importantly, appropriate funding.

- A phased approach would require setting interim targets that can be achieved over a prolonged time frame. Such an approach should clearly identify a number of milestones to ensure that progress is being made.

None of the remedial options are free of risks and any contemplated action will have certain benefits as well as certain negative impacts. Properly designed studies will highlight potential problems and provide some indication of the magnitude and significance of potential impacts. In effect, such studies will define the current state of the sediment environment.

In many areas, contaminated sediments have been an historical problem which needs to be resolved. The resolution starts with turning off the sources and, with the help of natural processes, improving the situation. In some cases the problem is so severe that additional efforts will be required to speed up the environmental healing process. Those involved in remediation should be aware that restoration to "pristine" conditions is usually an untenable and often unattainable goal, as is the expectation that immediate results can be obtained. As noted earlier, many areas will require an extended period of time, even with active remedial efforts.

On the other hand, a "do nothing" approach just for the sake of ignoring a problem is not acceptable. In the past, decision making was often delayed as additional information was sought to answer questions as they arose. In many cases, there are no immediate answers to such questions and if we try to answer every scientific question that arises, decisions will seldom be made. Therefore, it is imperative we work with the types of information gathered, recognizing that definitive answers are rarely provided given the current state of the science in information gathering.

Efforts should be directed towards addressing the essential questions:- How much cleanup is needed? Where is it needed? How much will it cost? How can it best be done? The section that follows addresses remedial options.

SECTION FIVE---SEDIMENT REMEDIATION OPTIONS.

5.1 REMEDIATION OPTIONS.

In most cases the choice of remedial options will depend on the nature of the contaminants and the severity of contamination. Where immediate cleanup is

required as a result of high concentrations and severe biological effects, the range of options may be more limited than in areas where contamination is less severe.

Nevertheless, a broad range of options is available for dealing with contaminated sediments and these have been summarized in Figure 4. These range from simple removal technologies to elaborate in-situ treatment. Predictably, as the complexity of the treatment increases, so do the associated costs, and the most elaborate methods are usually also the most expensive.

Sediment remediation technologies fall into three broad categories: A) Natural remediation; B) removal, sometimes followed by some type of treatment and; C) in-situ treatment. Currently, only the first two options have been used on a large scale and can be considered as proven technologies.

The selection of a remedial option requires careful consideration to ensure that any actions taken do not exacerbate the problem. In some situations, in-situ contamination may pose only a minor threat to organisms when in-place, particularly if the material is isolated from the water column, but may become a major concern when disturbed. Removal operations may resuspend contaminated material, thus potentially increasing its availability to aquatic organisms. Removal may also expose deeper layers of contaminated material. Finally, removal will present other concerns since in most cases this will require some type of secure disposal or additional treatment.

5.1.1 Natural Remediation

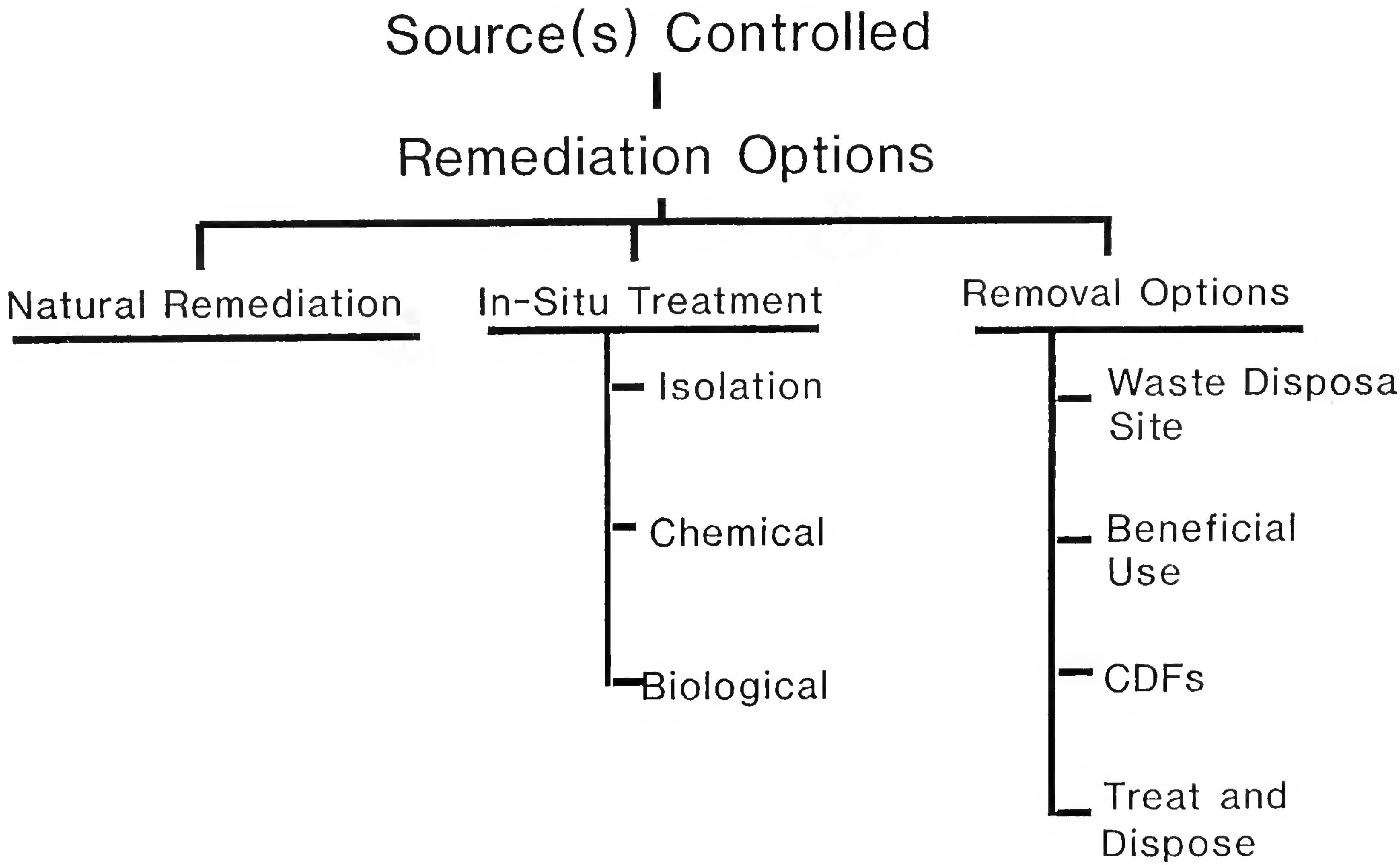
Natural remediation can be considered in those situations where the problem is not so severe that material must be removed immediately. Natural remediation is a preferred option where large areas of relatively low contamination are considered. The economic costs of removing and treating such areas usually makes this the most viable option. However, in all cases, this option assumes that effective source control has been achieved.

Natural remediation consists of leaving the sediments in-place, to be buried by newer, cleaner material. "Treatment" relies on the finding that many of the contaminants in sediments undergo changes in the sediment. Metals, for example, will often mineralize over time, creating insoluble compounds. Organic compounds will usually degrade over sufficiently long time periods.

In some cases, leaving the material in place may effectively reduce the availability of contaminants. In particular, metal availability can be reduced through natural processes such as diagenesis and mineralization. Most organic compounds, even persistent organics,will decompose as a result of microbial action, though in some cases this process may be exceedingly slow. If the contaminated material is isolated from the water column by a cleaner surface layer, then it would pose little threat to aquatic organisms.

Therefore, for natural remediation to be an effective option the sedimentation rate must be high enough that the material will be covered to a depth required to isolate the material from the water column in a reasonable period of time.

Figure 4: Sediment Remediation Options



Remediation Options

Natural Remediation

Advantages:
- least likely to resuspend contaminants
- no sediment loss due to handling
- no disposal problems
- natural mineralization of metals
- natural decomposition of organics

Suitable for sediment with:
- chronic biological effects
- low bioavailability of sediment contaminants
- low potential for biomagnification

Not suitable for sediment with demonstrated:
- acute toxic effects
- high sediment contaminant bioavailability
- strongly bioaccumulative compounds

Requirements:
- depositional area
- sufficiently high deposition rate
- low potential for disturbance

Though often equated with the "do nothing" option there are significant differences between the two. The "do nothing" option does not consider natural burial, rates of sedimentation or severity of contamination. It is most often used where it is not technically feasible or practical to undertake remediation. Natural remediation is not a "do nothing" option but requires evaluation of existing conditions to ensure that sediment burial is achieved within a predefined period of time.

It is important to determine the dynamics (transport) of both contaminated sediments and clean sediments in order to determine

the acceptability of this option. If clean sediments are being continually deposited over historically contaminated sediments and point source controls have been achieved, this may be the preferred option. If however, contaminated sediments are being slowly or episodically removed and re-deposited elsewhere, other remedial options may have to be considered.

The advantages and limitations of this option have been summarized in the inset on page 34.

5.1.2 Removal and Disposal or Treatment

All remediation activities that involve removal of sediments require some type of dredging operation. Dredging can be accomplished using either mechanical or hydraulic dredges. Mechanical dredges include the familiar clamshell dredge, as well as a variety of other modified buckets and may be deployed from the shore or barge-mounted. All have the advantage of being able to remove sediment at in-situ densities with little additional entrainment of water. However, these dredges typically result in high turbidity from re-entrainment of settled material. For remediation of contaminated sites, this is often highly undesirable and necessitates the use of additional measures to contain the suspended material, such as silt curtains. In many cases, physical conditions within the water body preclude the effective use of these mitigation measures and alternative methods of dredging, such as hydraulic dredges, may be required.

Hydraulic dredges typically operate with a much lower turbidity than mechanical dredges. Hydraulic dredges are usually comprised of some type of cutting head that loosens the sediment and mixes it with water, and a pumping system that pumps the slurry either to a holding tank such as a barge, or through a system of pumps to a shore-based holding area. Hydraulic dredges typically entrain large volumes of water in order to achieve a pumpable slurry. Where clean sediments are being removed, as in the case of navigational dredging, the hopper or barge is allowed to overflow the excess water. For remediation of contaminated sediments, use of hydraulic dredges will necessitate treatment of entrained water since, due to the presence of contaminants, the water cannot be overflowed.

The removal equipment can vary in size, depending on the needs or access restrictions of the area. Most removal equipment has been designed to operate at practical depths of up to 10 m. In deeper water, removal of contaminated sediment may be limited by the availability of suitable equipment. While clamshell-type dredges are theoretically capable of operating at any depth, their accuracy can be substantially diminished at greater depths.

A number of new designs for removal equipment that minimize sediment loss have also been tested, including such specialized devices as the pneuma-pump. The following list of treatment options considers the technologies only in terms of broad categories. Within each category a number of different technologies exist, many of which are proprietary. Sources for detailed information on specific processes are available in a number of publications, including:

- *Review of Removal, Containment and Treatment Technologies for*

Remediation Options

Removal and Disposal

Advantages:
- removes toxic sediments

Suitable for sediments with:
- acutely toxic effects
- high bioavailability of sediment contaminants
- highly biomagnifying compounds
- high sediment resuspension

Not suitable for sediments of:
- suitable for all situations though too expensive to consider for areas of low sediment toxicity or bioavailability

Requirements:
- means of minimizing turbidity and loss during removal (e.g., silt curtains, specialized dredges)
- suitably engineered disposal site
- means of minimizing losses during handling and transportation

Remediation of Contaminated Sediment in the Great Lakes. (Avrett *et al.* 1990).

- *Sediment Treatment Technologies Database*. 2nd Edition. 1993. Wastewater Technology Centre, Burlington Ont.

- *Screening Guide for Contaminated Sediment Treatment Technologies.* Environment Canada, St. Lawrence Centre. 1993

Removal and Disposal

Once the contaminated sediment has been removed, a number of disposal options

can be considered. Depending on availability and local acceptability, the material could be disposed of in CDFs, in landfills, or hazardous waste landfills. In many cases, however, to keep disposal costs down, pretreatment of the material (i.e. prior to disposal) will be required. The advantages and limitations of this option are summarized in the inset on page 36.

1. Dredging, Dewatering, Solidification and Disposal. This option involves the removal of the sediment, subsequent dewatering and solidification and disposal in an acceptable site.

- primarily for dredging of sediment defined as hazardous material.
- removal usually requires hydraulic dredging or, if conventional dredging is used, additional containment devices such as silt curtains will be necessary.
- hoppers cannot be overflowed and entrained water must be treated prior to return.
- mechanical dewatering consists of: filters, centrifugation, or thickening.
- evaporation dewatering: requires energy input for evaporation and will require treatment of off-gases.
- choice of dewatering depends on amount of sediment, available temporary storage for material awaiting processing, and desired consistency of the material (depends on disposal alternative).

Removal and Treatment

Most of the post-removal treatment technologies currently developed or being tested fall into one of three major groups: 1) Extraction processes, which involve dissolution of the contaminant in a recoverable fluid; 2) Immobilization processes which chemically fix or alter the contaminants and; 3) Thermal processes which use heat to break down the chemical bonds of the contaminants or to vitrify contaminants and sediments into a solid mass. The advantages and limitations of this method are summarized in the inset on the following page.

Few of the methods proposed or tested attain total destruction or removal. The most efficient technologies currently range from 80% efficiency for metals, to in some cases 99% efficiency for organics, though typically these are much less. However, in most cases, the residue will still contain contaminants and only in those cases where concentrations are at or below MOEE's guidelines for open water disposal (PSQGs; Persaud *et al.* 1993) can the material be safely returned to the aquatic environment. In most cases, the material will have to be disposed of upland in accordance with MOEE's requirements such as Reg. 347 and the Proposed Materials Management Policy.

1. Dredging and Washing/Extraction.

Following dredging, the materials are subjected to washing with various solvents that will preferentially bind target contaminants. The solvents are subsequently separated from the sediment. In theory, the cleaned material can be returned to the site, though in most cases it will have to be disposed of at an appropriate upland site. However, since the material will have lower contaminant concentrations at the end of treatment, a larger number of disposal options will be available.

- contaminated sediment is washed in a suitable solvent to remove the contaminants. The solvent is later recovered.

Remediation Options

Removal and Treatment

Advantages:
- removes toxic sediments
- removes/ destroys toxic compounds
- eliminates need for expensive containment (still requires on-land disposal)

Suitable for sediments with:
- acutely toxic effects
- high sediment bioavailability
- highly biomagnifying compounds
- high sediment resuspension
- compounds for which removal/destruction technologies exist

Not suitable for sediments of:
- suitable for most areas though too expensive to consider for areas of low sediment toxicity or bioavailability

Requirements:
- means of minimizing turbidity and loss during removal
- large areas set aside for extended time for equipment and stockpiling of sediment

- solvents can be selected to remove either organics or inorganics (because of the different solvents required for each, it does not appear to be feasible to do both at the same time and removal of both will require multiple steps).
- requires a storage area and a treatment facility (i.e., tank of some kind).
- most processes require multiple extraction cycles.
- requires further separation of

contaminants from solvent and final disposal of contaminant concentrate.

2. Dredging and Incineration/Thermal Destruction

The material is dredged, usually dewatered to some degree and incinerated in high temperature incinerators.

- are among the more effective options for destroying organic contaminants. (up to 99% efficiency of removal)
- incinerators include: fluidized bed, circulating bed combustor, high-temperature slagging, infrared, multiple hearth, plasma arc, Pyretron, and rotary kiln.
- not effective for metals - volatile metals like mercury and lead may require additional steps to ensure removal from flue gases. Incineration can also change oxidation states of some metals, making metals in the final product more mobile.

2a. Dredging and Vitrification.

The material is dredged, dried to some degree and treated. The treatment uses high-voltage graphite electrodes to melt material. The molten material then cools to a solid glass-like material.

- does not measurably leach organic or inorganic contaminants.
- energy costs are high (depending on water content) as are operating costs (consumable electrodes).
- may require flue gas collection and treatment since process volatilizes semi-volatile and volatile organics.
- bench-scale tests confirmed better than 99% efficiency in PCB destruction.

2b. Dredging and Low-temperature Thermal Stripping.

Sediments are heated to relatively low temperature (ca. 350° C) to remove volatiles and semi-volatiles. The volatiles are condensed and the liquid cleaned and filtered through activated carbon.

- the dry, dust-like sediment will contain materials not driven off by low temperature.

2c. Dredging and reductive dechlorination.

Sediments are heated in the presence of a reducing agent such as hydrogen to dechlorinate organic contaminants.

- suitable for only a certain number of organic compounds (currently tested only for PAH and PCBs).
- better than 99% efficiency for those compounds tested (PCB and PAH).
- has currently been tested only in pilot and bench scale tests.

3. Dredging and Biological Treatment.

Uses biological methods such as slurry-phase biodegradation. Most available methods rely on bacteria to decompose organic contaminants, either under aerobic or anaerobic conditions. May require inoculation /addition of bacteria.

4. Dredging and Chemical Fixation (Immobilization)(Solidification/Stabilization) These involve a number of methods to limit contaminant mobility through introduction of a chemical fixative. While most require removal of the sediment, some procedures have been proposed for in-situ fixation.
   - most effective for treating heavy metal contamination.
   - involves injecting a solidifying agent (e.g., cement or lime) together with an additive to prevent organics from interfering with the solidification process.

5. Dredging and Chemical Treatment
Involves treatment with any of a number of chemicals to neutralize, fix, or alter contaminants in sediment.
- chelation uses chelating molecules to bind and restrain metal ions from forming ionic salts.
- efficiency is variable, depending on chelating agent and dosage.
- other processes include oxidation of inorganics, nucleophilic substitution.

6. Dredging and Multi-phase treatment.
a combination of the above treatments.

5.1.3 In-Situ Treatment.

A limited number of options are available for in-situ treatment of contaminated sediment (the advantages and limitations of this option are summarized in the inset on page 41). Some, such as in-situ fixation have not been demonstrated on a large scale, though preliminary work (Pers. Comm.; T Murphy) indicates these may be a practical means of dealing with extensive areas of sediment contamination where active sources still persist or where particular compounds amenable to this type of treatment occur. In-situ fixation methods work mainly through aiding natural remediation processes such as decomposition of organics in order to reduce, though not necessarily eliminate, sediment contamination.

1. Capping
The procedure involves covering existing contaminated sediment with clean material.
- unless capping material is less dense than material being capped, the materials may sink through.
- potential for erosion of cap materials
  - reduces navigable depth and precludes future dredging.

2. In-Situ Fixation/Stabilization
Involves the injection of chemicals/additives that will either bind with contaminants to effectively remove them from circulation, or that enhances their decomposition.
- this is at present only in the developmental stages and has not been demonstrated in full scale.

3. Capping-Lakefilling (Overfilling)
This is similar to capping except that the area is isolated and the cap extends to the surface to create a lakefill.

In addition, a number of new technologies are being evaluated, though presently none of these have been used in the actual cleanup of a site. Only some have undergone bench tests and fewer still have undergone pilot-scale tests.

5.2 SELECTION OF REMEDIAL OPTION

Once the available options have been identified the next task is to determine which are most suitable for the site in question. Initially, it needs to be determined whether active remediation is a realistic or feasible goal. Some areas for example may be prohibitively expensive and may best be left to natural remediation.

The evaluation of remedial options should include:
- level of contamination and severity of biological effects (some options are not suitable for heavily contaminated/ acutely toxic sites) see

Remediation Options

In-situ Treatment

Advantages:
- eliminates need to remove and treat/ adequately dispose of toxic sediment
- reduces sediment losses through removal and handling

Suitable for sediments with:
- contaminants for which treatment technologies exist
- suitable physical conditions (e.g., for capping)
- ongoing existing sources
- where removal is impractical

Not suitable for sediments of:
- unstable bottom conditions or untreatable chemical compounds
- where rapid removal/isolation required

Requirements:
- contaminants must be amenable to chemical treatment
- must effectively complex/isolate contaminants within a suitable time frame

Figure 5.

- volume and type of material to be remediated.
- physical factors such as navigational use (see Figure 6).
- suitability of treatment(s) to the type(s) of contaminant(s) (where different classes of contaminants are involved, e.g., organics and metals, treatment may involve different processes for each that may have to be done in series).

Figure 5: Potential Remedial Options Based on Biological Effects

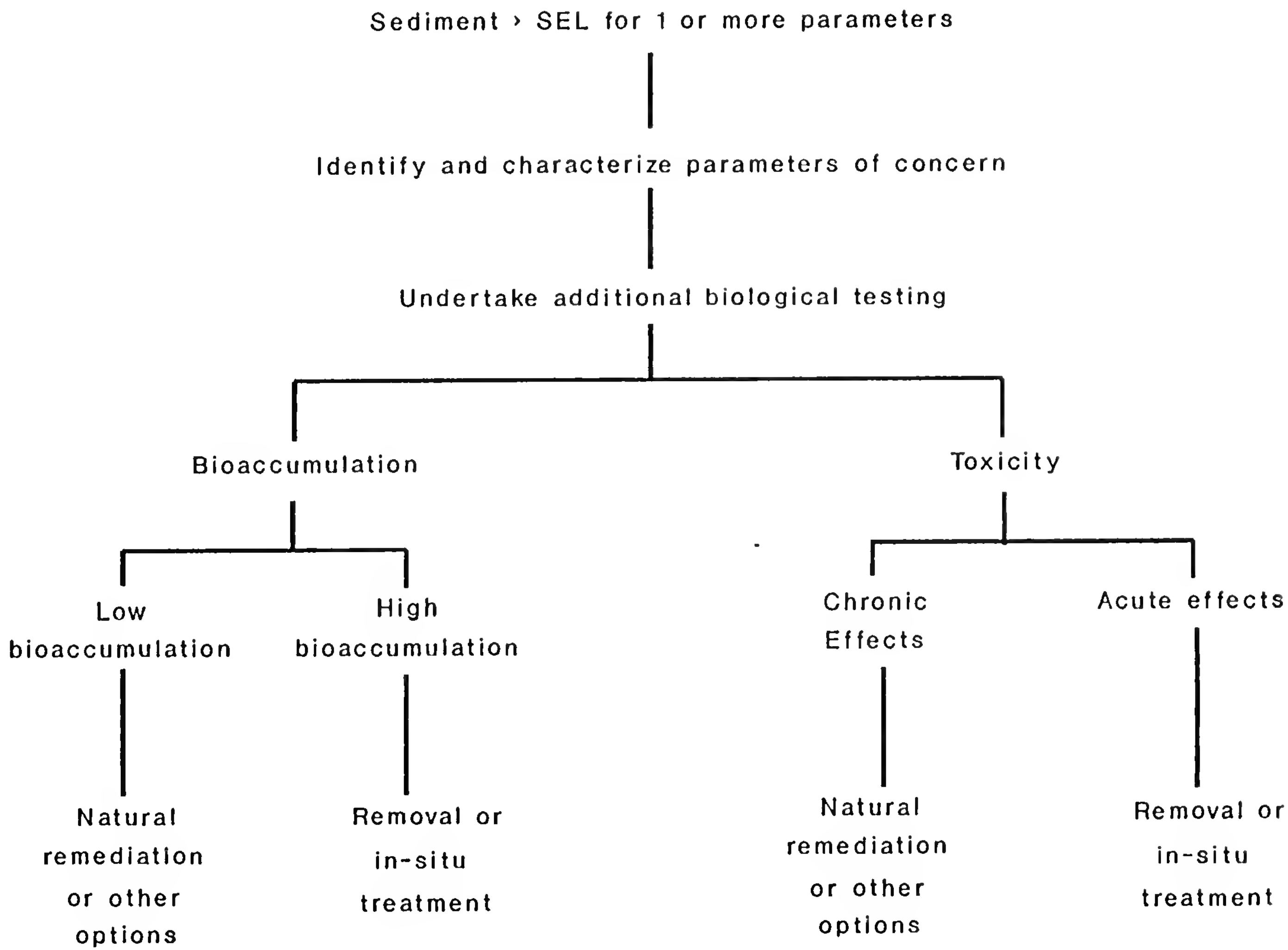
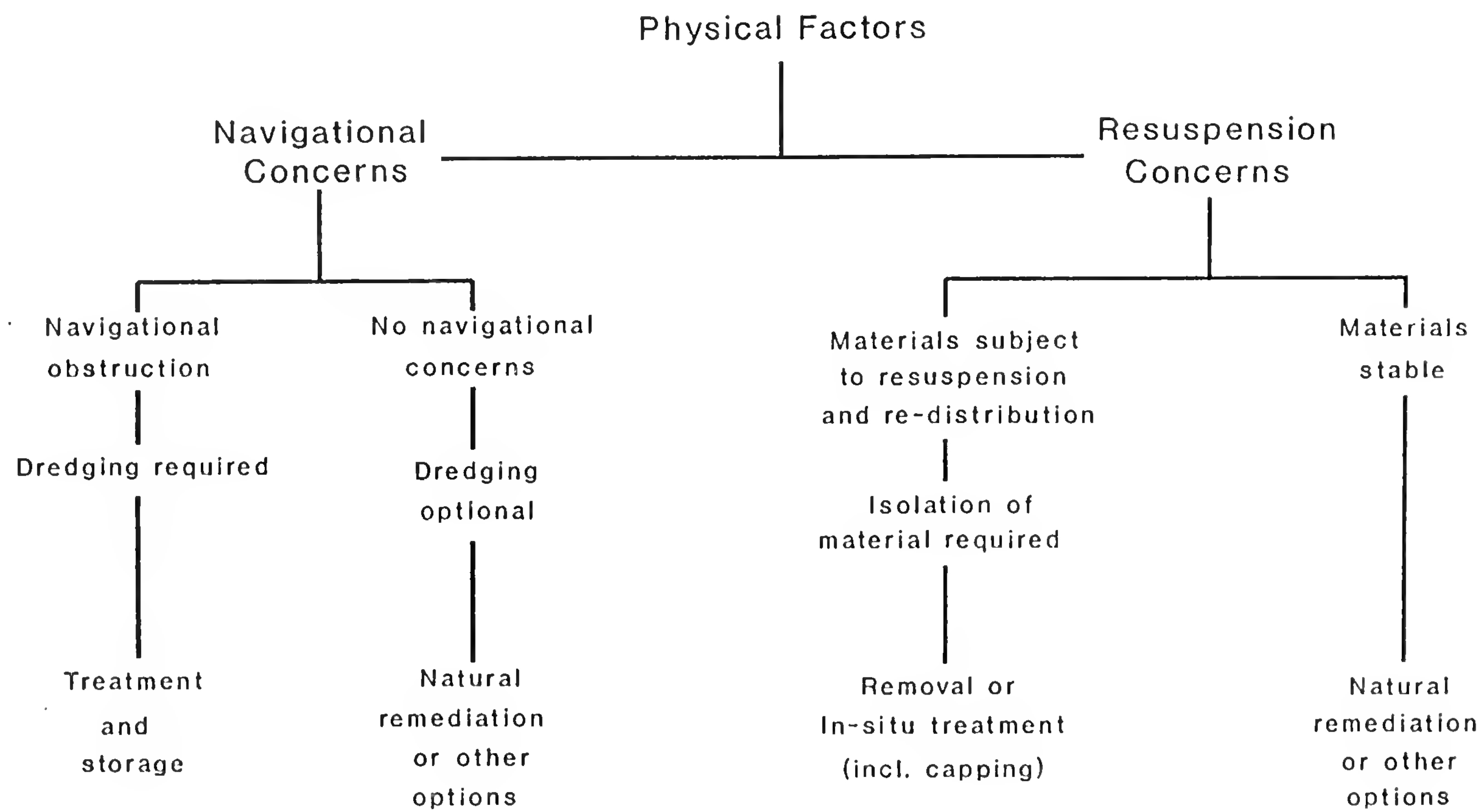


Figure 6: Selection of Remedial Options Based On Physical Factors



- effectiveness of remediation and /or treatment (i.e., will the method remove only some or all of the contaminant of concern; will additional treatment or some type of confined disposal be required; will some steps have to be repeated).
- costs for remediation, including removal, treatment and storage.
- mitigation procedures required.
- potential for reuse of material.
- potential disruptions to current uses of the area (e.g., will navigational routes be affected, disruption/ destruction of fish habitat).
- length of time required for the project.
- public acceptance of the option.

A table should be prepared that lists thevarious options and the evaluation criteria. The most suitable option would then be identified through determination of which option not only meets the remediation target, but also most closely satisfies the priorities developed for the particular area.

Evaluating Cleanup Options

In evaluating the different options for sediment cleanup, consideration must be given to the "non invasive" option of natural remediation which, as mentioned earlier, relies on clean sediments depositing over the contaminated area through natural processes. The natural remediation option may be the preferred option in those cases where other forms of remedial action may result in a worsening of the situation by making contaminants more readily available through resuspension and dispersion. The natural remediation option would best be considered in depositional areas such as harbours where incoming clean sediments will form a cap over the contaminated material. This will apply to those areas where the sources have been controlled.

A convenient way of summarizing information to be used in deciding on a remedial option for contaminated sediment could be through construction of a matrix as shown in the following hypothetical case.

Evaluation Parameters	OPTIONS 1	2	3	4	5
Cost Effectiveness	H	M	L	M	H
Uses Ecosystem Principles	M	L	M	L	L
Social Acceptability	M	H	M	L	L
Technical Feasibility (Based On Type And Quantity of Material)	L	M	H	H	H

Prioritizing Options:

These have to be developed on a site specific basis, since local priorities will differ. However, cost and technical feasibility are typically major determining factors, and further evaluation of an option is usually not warranted if the option is technically unsuitable or the cost is prohibitive.

Cost Effectiveness:

Cost effectiveness refers to the financial costs of achieving the desired or stated objectives on sediment cleanup for each of the options being considered.

As a basis for comparison, the natural remediation option can be used as a baseline. Costs must include all facets associated with the option, including -:

equipment, mobilization, removal, treatment, residuals disposal, etc. This has to be done for each phase of a multiphased operation and must also include any post cleanup costs associated with management of material removed.

Ecosystem Principles:
The basic element in such principles is that extreme caution is used to ensure that a sediment cleanup operation does not result in the transfer of contaminants to another area where they pose a threat. In most situations, when sediment is removed from water it is placed in a confined disposal facility along the shoreline or is disposed of at an upland site.

Social Acceptability:
This includes public response to the measures being proposed as reflected through public advocates on the decision making team. Concerns may be related to the cost of the project, the effort and anticipated accomplishments (e.g. is it a partial or full cleanup effort? will it take an inordinately long time to effect? Will the proposed solution create problems in other areas (e.g. will material have to be disposed of on land with potential to affect existing land use or environmental quality?).

Technical Feasibility\ Implementability:
The method selected must be capable of dealing with the problem without generating any problems of its own, e.g. if dredging is required, then the type of dredge selected should minimize the loss of material through resuspension and dispersion. The size and type of equipment used must fit the problem and the area.

5.3 REMEDIATION PLAN

The final step, once the remedial options have been identified, is the development of a remediation plan. This will identify the impaired uses, the remediation targets, and the means of achieving these targets. Included in the latter should be any mitigative measures needed to ensure that any adverse effects of the remediation are minimized. This step will also need to identify the means of disposal of the material, and the final best use for the area.

The final remediation plan is based on the results of both the sediment and biological studies and is developed in conjunction with socio-economic considerations. The steps to development of a remediation plan are listed below:

1) Identify the impacts- this will identify both biological/chemical impacts and socio-economic impacts (such as impaired uses, etc.)
2) Determine area to be cleaned up. This is based also on both scientific and socio-economic criteria.
3) Determine options for remediation. This should list all suitable options.
4) Identify the benefits and costs of each option on both an environmental and an economic level.
5) Determine the most appropriate cleanup strategy, which may not always be the most desirable from a purely scientific perspective.
6) Develop a detailed plan for remediation, identifying all the major steps and a timetable for implementation. These include the details of removal or in-situ treatment such as schedules, areas, volumes to be treated or removed, temporary and permanent disposal sites,

etc.

It is at this level that the truly hard choices must be made. At the earlier steps in this procedure, the scientific criteria have been determined, and the best environmental solutions have been developed. *It is unfortunately true however, that the best scientific solutions are not always the most practical. The costs of each option must be weighed against the benefits, and the choice made may not be the best from an environmental perspective.* Although it is beyond the scope of this document to describe the socio-economic process associated with sediment cleanup, it is nevertheless a major component of the decision making process and the proper expertise must be obtained to conduct such an assessment.

A number of remediation options are suitable only for certain types of contaminants, or are practical only for low volumes of material. If removal and off-site confinement are considered, then it is necessary to evaluate the safety and integrity of the confinement site. Not all material is suitable for such storage.

In many cases, material will be suitable for alternative upland uses. The Materials Management Policy (MOEE - in prep.) identifies a number of classes of material. Dredged material should be evaluated according to the process outlined in the Policy to determine suitability for disposal in sites other than registered landfills or hazardous waste sites. This will reduce disposal costs as well as conserve scarce disposal areas.

SECTION SIX--SEDIMENT CLEANUP

6.1 IMPLEMENTATION OF REMEDIATION PLAN

Once the remediation plan has been developed and approved by all concerned, the plan needs to be implemented. During actual implementation of the plan, all efforts need to be directed towards ensuring that the approved plan is followed, with as little deviation as possible. Some deviations will always be necessary, as unforseen situations arise. A mechanism for resolving such problems should also be in place, to ensure that the task can be completed quickly. In many cases, the danger of contaminant release or escape (with often broad dispersal) is heightened by prolonging the construction /remediation period.

In all cases, once remediation is underway, a site manager should be present at the site to ensure the remediation plan is being followed, and to deal with unforseen situations as these arise. The site manager should have overall responsibility for the cleanup actions.

In many cases the specific precautions taken to minimize adverse effects will depend on site-specific considerations. This will be dictated by considerations such as the actual method of removal, the methods of treatment and the means of disposal.

Examples include:

- special handling procedures
- special dredging techniques
- treatment of overflow water from hopper
- silt curtains or other sediment containment devices

Of the intrusive remediation options, in-situ remediation is usually the least disruptive. Depending on the methods used, some disturbance of the surface layers can be expected, though the effects will usually be localized to the immediate area.

Loss of sediment during the dredging operation is a major concern with removal of contaminated sediment. Loss of material to the water column has the potential to distribute contaminated fine material over a broad area, which can also heighten the bioavailability of contaminants to aquatic organisms. The major concern is to control such losses, either through the use of special cutting and dredging devices that minimize the amount of material that is resuspended, or through the use of additional equipment such as silt curtains that can limit the spread of resuspended material. Both methods have their limitations. Special cutting heads for use with suction hopper dredges will require additional facilities for treatment of entrained water, since these types of dredges typically require high water content in order to remove the material. Silt curtains are suitable for use only in areas of little or no current and during calm weather.

In flowing water situations removal operations may be carried out in the "wet" or "dry". The type of removal operation will depend on the size and flow of the stream or river. In large rivers sediment removal will be carried out using the same equipment as used in standing water (dredges) though containment devices such as silt curtains are often unsuitable in these situations. In smaller rivers and streams, sediment control measures may require the placement of temporary barriers to control resuspension. In some cases the isolation of the contaminated area through the construction of cofferdams and dewatering of the site may be the most preferable.

The actual removal of contaminated sediment can result in a number of adverse effects in shoreline areas through losses of material. Such problems are heightened each time that the material is handled. Such activities are also disruptive to shoreline and navigational uses of the area as heavy equipment is brought in. Most areas will require a shoreline staging area, as well as temporary materials storage and sediment dewatering facilities. Some of the newer technologies will require extensive areas set aside for considerable periods of time for treatment facilities, and most will require transport to a final disposal site. Each of these steps has the potential to result in adverse effects from loss of material. Proper containment devices will be required as well as protective measures for site workers.

Contaminated sediments present special transportation problems. Materials dewatered and treated on the site should be transported in covered containers to minimize losses as wind-blown dust. However, wet materials moved off the site for treatment or disposal must be transported in sealed trucks or other containers.

Temporary or final storage needs must be determined on a site specific basis since this depends on the material involved (i.e. how toxic), the volume, treatment needs, and any possible end-uses after treatment. Storage facilities should be designed to address these specific concerns.

During cleanup, a site supervisor should be present at all times to monitor activities at the site. The supervisor needs to be fully aware of the potential problems and fully

appraised of the details of site cleanup.

SECTION SEVEN--POST-REMEDIATION

7.1 MONITORING EFFECTIVENESS OF REMEDIATION

An essential element of any cleanup operation is a measure of its effectiveness. Assessment of the effectiveness of the operation should include all of the parameters/uses that were identified as impaired, as a measure of achieving the remediation target. The study can also include additional tests, which may indicate whether the cleanup has resulted in additional effects that may not have been anticipated.

Where chemical criteria were used as targets, biological monitoring should be employed as well. For example, monitoring may reveal that there are no biological impacts despite sediment concentrations in excess of the LEL.

The assessment should also determine whether the "local best use" identified earlier is now achievable. This may not be readily apparent, since any area that has undergone remedial action will require a period of time to stabilize.

Finally a decision must be made on the long term monitoring of the area: how frequently, and for how long such monitoring should be continued, and when can it be stopped, are questions that need to be addressed. In many cases, such long term monitoring should be instituted some time after the initial post-cleanup assessment in order to measure effects after the area has stabilized. A time period of three to five years between sampling is recommended.

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Figure 7: Summary of Sediment Remediation Process

Sediment >SEL for 1 or more parameters

Identify and characterize parameters of concern

Identify and control sources

Determine biological effects

Effects severe and warrant remediation

Define area and volume of sediment affected

Define impaired beneficial uses

Determine local "best uses"

Develop remediation options

Develop remediation targets

Select most suitable remediation option

Implement remediation plan

Monitor effectiveness of remediation
(assess impaired uses)

Implement long term monitoring plan